Numerical Studies of Rough Surface Scattering Models

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LONG-TERM GOALS

To develop a practical set of rough surface scattering strength equations for use in real-world Navy applications.

OBJECTIVES

To examine and develop theoretical surface scattering models that accurately predict acoustic wave scattering at the air-sea interface and at the ocean-bottom interface.

APPROACH

We have focused our attention on the development and examination of two theoretical models for rough surface scattering, the small slope approximation (SSA) and the non-local small slope approximation (NLSSA). The SSA has been developed for scattering from the ocean bottom, and the NLSSA has been developed for scattering at the air-sea interface.

WORK COMPLETED

The SSA has been developed for Biot theory. Scattering equations have been derived, and numerical results have been obtained for the backscattering and scattering strengths. A heuristic approach has been used to approximate the NLSSA scattering cross section, and numerical results have been obtained for the scattering strength.

RESULTS

The SSA equations for rough surface scattering using Biot theory were derived. Numerical results for the lowest-order SSA were obtained for both backscattering and bistatic scattering using a modified power law spectrum, and these results were compared with those of lowest-order perturbation theory (PT). Frequencies ranging from 100 Hz to 3 kHz were used for surfaces with *rms* heights h of 0.1 m and 1 m and a correlation length l of 10 m. The angle of incidence for the bistatic results was limited to 45°. It was found that for the smaller surface height roughness ($h = 0.1$ m), the SSA and PT give the same results for frequencies up to almost 1 kHz for both backscattering and bistatic scattering. For $h = 1$ m,

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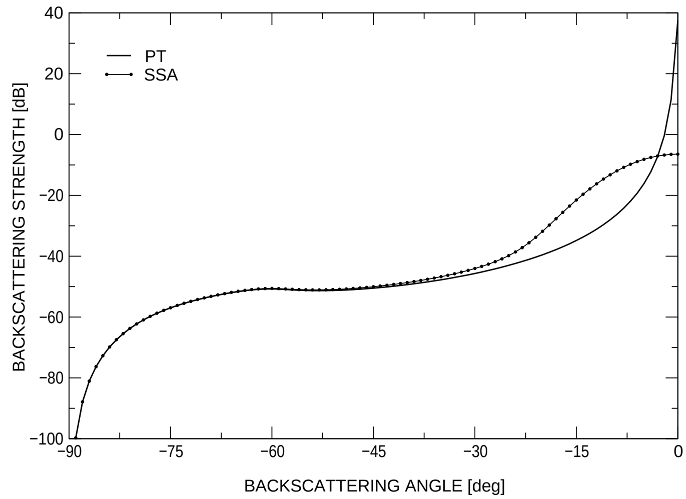

Figure 1: Backscattering strengths for lowest-order PT and SSA. The surface parameters $h = 1$ m and $l = 10$ m, and the frequency is $f = 3$ kHz (or $kh = 12.57$, $kl = 125.66$, where k is the wavenumber).

the SSA and PT backscatter results are in good agreement at all frequencies for incident grazing angles up to approximately 45°. For the bistatic results, the SSA and PT results agree only at low grazing angles of scatter. Figure 1 shows numerical results for the backscattering strength when $h = 1$ m and $l = 10$ m at a frequency of 3 kHz. These results were presented in Newport Beach, California, at the meeting of the Acoustical Society of America in December 2000, and a paper has been submitted to the *IEEE J. Oceanic Engineering.*

Voronovich introduced the NLSSA as a generalization of the SSA to explicitly include non-local interactions [1]. He showed that the NLSSA generally accounts for double scattering in the high frequency limit. Broschat and Thorsos presented numerical results for the lowest-order NLSSA scattering strength for two-dimensional, pressure-releases surfaces [2]. Their results agreed well with Monte Carlo integral equation results and, in particular, were better than the higher-order SSA results at low forward grazing angles. However, the computational cost was extremely high, and results were unobtainable at low grazing angles. We have made an *ad hoc* approximation to the lowest-order NLSSA scattering cross section that reduces the computational complexity of the integration substantially. In addition, the first term of this approximate form is identical to that of the lowest-order SSA. Numerical results for the scattering strength were obtained for 2-D, pressure-release surfaces, and for the cases examined, the NLSSA and its approximate form give virtually the same results. Results at low grazing angles are obtainable and accurate with the approximate form. These results were presented in Newport Beach, California, at the meeting of the Acoustical Society of America in December 2000. Figure 2 shows numerical results for the bistatic scattering strength for $kh = 1$ and $kl = 1.4$ where k is the wavenumber, h is the *rms* surface height, and l is the surface correlation length. The spectrum is Gaussian, and the incident angle is 45°. Results are presented for the integral equation method (courtesy of Eric Thorsos), the SSA (both lowest order and higher order), the NLSSA, and the approximate form of the NLSSA (ANLSSA). It is believed that the surface parameters of this example give rise to double scattering.

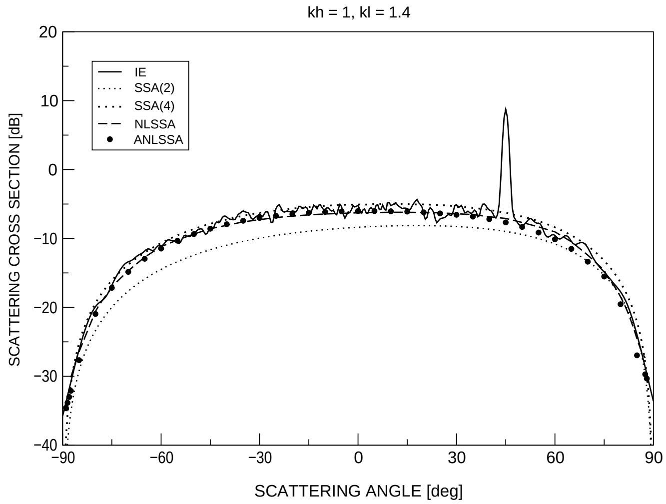

Figure 2: Scattering strengths for the integral equation, SSA, NLSSA, and approximate NLSSA. The normalized surface parameters are $kh = 1$ and $kl = 1.4$, where k is the wavenumber, h is the rms surface height, and l is the correlation length.

IMPACT/APPLICATIONS

The development of approximate models that accurately predict wave scattering from rough surfaces is important in a number of Navy applications. For example, rough surface scattering models are needed in the simulations used by torpedo guidance and control personnel to test torpedoes. Another application for which rough surface scattering is critical is the detection of underwater mines, especially those buried in soft sediments. Other applications include ship wake detection, communications, and anti-submarine warfare. Of particular importance is that the models be as simple as possible while retaining the physical information necessary for the application.

TRANSITIONS

Much of the knowledge we have gained has been disseminated via publications and conference presentations. A search of the Science Citation Index online shows that previous ONR-sponsored work published in the *Journal of the Acoustical Society of America* has been cited about 60 times; it is believed that the current work will also be of use to others.

RELATED PROJECTS

This work is related to research in shallow water acoustics, high-frequency acoustics, and long-range propagation. The SSA Biot work is especially relevant to high-frequency, shallow water acoustics where the question of acoustic penetration into sediment is of much interest. The NLSSA work is relevant to long-range propagation since it attempts to model accurately scattering in the forward direction. Additionally, this work is related to that of several other ONR-sponsored researchers including Eric Thorsos and John Schneider.

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